International Journal of Electrical and Computer Engineering (IJECE)
Vol. 5, No. 5, October 2015, pp. 939~947
ISSN: 2088-8708

Design Calculation of Parabolic Trough Solar Thermal System and Three-phase Turbo Alternator

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Article Info

Article history:

Received Apr 14, 2015
Revised Jul 10, 2015
Accepted Jul 22, 2015

Keyword:

Exit temperature
Parabolic trough collectors
Synchronous generator
Thermal storage
Useful heat gain

ABSTRACT

Solar energy can be converted into thermal energy with the help of solar collectors. Electricity can be produced directly from solar energy using photovoltaic devices or indirectly from steam generators using solar thermal collectors to heat a working fluid. This research is using the conversion of solar energy into electricity in a closed cycle driven by natural convection. It would mean that electricity is cheaper than from any other renewable technology and cheaper than from fossil fuels. This paper describes converting thermal energy collected by solar collector to electricity by using turbine. Anywhere in Myanmar will cheaply use electricity by using solar turbine generator. Remote areas will improve more and more when getting the efficient electricity. The design calculation and performance predication of 1 MVA turbo-alternator/generator are also mentioned. Design calculation of absorbed flux, useful heat gain and exit temperature is described. And then development of two-tank thermal storage system that uses molten salt as the heat transfer fluid is described.

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1. INTRODUCTION

There are three types of solar thermal generation in general. They are parabolic dish, parabolic trough, and central receiver or power tower system. The cornerstone of solar parabolic trough plant is the solar field. The solar field consists of parabolic trough collectors and piping. Parabolic trough collectors can be divided into two subsystems: the solar collection assembly (SCA) and the heat collection element (HCE). The SCA also includes the single-axis tracking equipment and support structure for the HCEs. During operation, solar radiation is reflected from the SCA onto the parabolic trough's focal line, where the HCE resides [1-2].

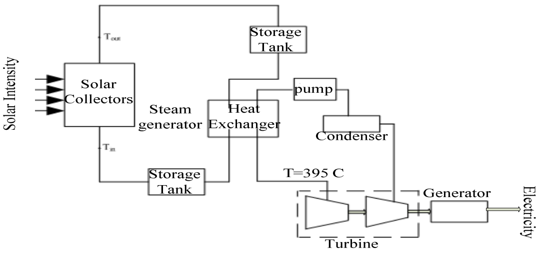

Figure 1. Schematic Diagram of Parabolic Trough Solar Thermal Electrification

The steam is used to describe the heat exchangers that heat the working fluid, highly pressurized water, from a compressed liquid state into a superheated vapor statein Figure 1. The preheated warms the working fluid from compressed liquid to saturated liquid. Due to the latent heat of evaporation the steam generator is the most energy intensive heat exchanger. This paper describes converting thermal energy collected by solar collector to electricity by using turbine. Anywhere in Myanmar will cheaply use electricity by using solar turbine generator. Remote areas will improve more and more when getting the efficient electricity [3].

2. DESIGN CALCULATION

Geometry of Wyargyi Village

Wyargyi village is situated between North Latitude 20˚ 25´ and East Longitude 96˚ 09´. The elevation above sea level is 74.676×10^{-3} m and situated Mandalay Region within tropical zone. The local standard time of meridian is 97˚ 30´ E. The temperatures, sunshine hour, and total solar radiation of Wyargyi village for the year 2014 are maintained in Table 1 and Table 2. The data are obtained from Department of Meterology and Hydrology (Myanmar – Wyargyi village). Figure 2 shows variation of solar intensity and time. [4].

Table 1. Temperatures (℃) and Sunshine Hour of Wyargyi Village

Month	Temperature ℃	Sunshine hour
January	31.7	7.8
February	36.3	9.5
March	38.5	9.2
April	40.1	10.8
May	35.6	11.2
June	34.0	9.3
July	33.0	9.0
August	31.4	9.2
September	32.2	9.0
October	31.4	8.5
November	31.3	7.4
December	27.8	6.8

Table 2. The Total Radiation for Horizontal Surface

Time (hr)	Temperature ℃	Sunshine hour
6-7 am	0.29707	1.11567×10^{-5}
7-8 am	0.92317	0.41511
8-9 am	1.49227	0.995211
9-10 am	1.5875	1.53001
11-12 am	1.99767	1.9236
12-1 pm	2.21167	2.1305
1-2 pm	2.21167	2.1305
2-3 pm	1.99767	1.9236
3-4 pm	1.5875	1.53001
4-5 pm	1.49227	0.995211
5-6 pm	0.92317	0.41511
6-7 pm	0.29707	1.11567×10^{-5}
Total(MJ/m^2)	17.0187	13.9888
(W/m^2)	4727.4166	3885.8011

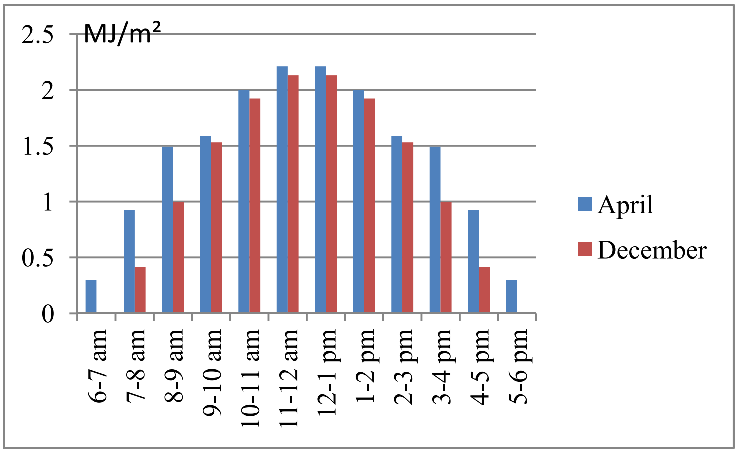

Figure 2. Variation of Solar Intensity and Time

3. DESIGN CALCULATION DATA OF PARABOLIC TROUGH

Date April 15 =40.1℃ and December 15= 27.8℃

The data in table 2 are used and calculated with the following equations for design calculation of parabolic trough. Design calculation results show in table 3.

Specular reflectivity of the concentrator surface, ρ	0.94
Glass cover transmittivity for solar radiation, τ	0.88
Absorber tube emissivity /absorptivity, α	0.96
Intercept factor, γ z	0.95
Mass flow rate of water, m	0.09 kg/s
Inlet temperature	60˚C

The equations of absorbed flux, useful heat gain, and exit temperature

$$S = I_b r_b \rho \gamma \left(\tau\alpha\right)_b + I_b r_b \left(\tau\alpha\right)_b \left(\frac{D_o}{W - D_o}\right) \tag{1}$$

$$q_u = F_R \left(W - d_{co}\right) L \left[S - \frac{U_L}{c}\left(T_{fi} - T_a\right)\right] \tag{2}$$

$$mc_p \Delta T = q \tag{3}$$

Table 3. Results of Absorbed Flux, Useful Heat Gain and Exit Temprature in April and December

Time (hr)	S (W/m^2)		Q (kW)		T$_{fo}$ (℃)	
	April	December	April	December	April	December
6-7 am	64.2859	2.4142	89.2860	-72.7649	60.1603	59.8694
7-8 am	199.7741	89.8298	378.8027	114.0283	60.6799	60.2047
8-9 am	322.9273	215.3638	641.9615	382.2744	61.1522	60.6861
9-10 am	343.5351	331.0943	685.9971	629.5721	61.2312	61.1299
10-11 am	432.2959	416.2672	875.6648	811.5730	61.5716	61.4566
11-12 am	478.6056	461.0404	974.6213	907.2462	61.7492	61.6283
12-1 pm	478.6056	461.0404	974.6213	907.2462	61.7492	61.6283
1-2 pm	432.2959	416.2672	875.6648	811.5730	61.5716	61.4566
2-3 pm	343.5351	331.0943	685.9971	629.5721	61.2312	61.1299
3-4 pm	322.9273	215.3638	641.9615	382.2744	61.1522	60.6861
4-5 pm	199.7741	89.8298	378.8027	114.0283	60.6799	60.2847
5-6 pm	64.7741	2.4142	89.2860	-72.7649	60.1603	59.8694
Total	3682.8478	3032.0194	7292.6668	5543.8582	733.0888	730.03

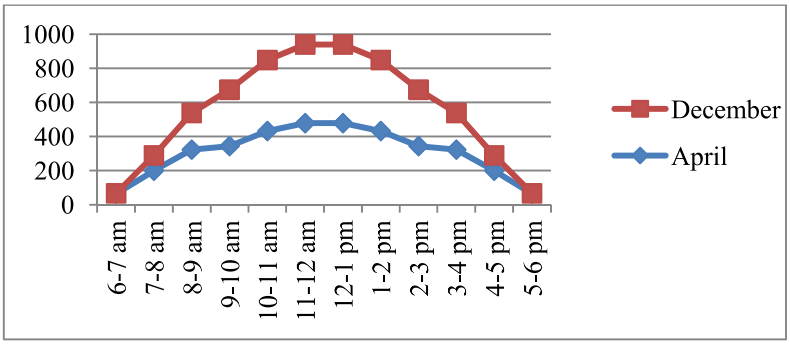

Figure 3. Results of absorbed flux, S in April and December

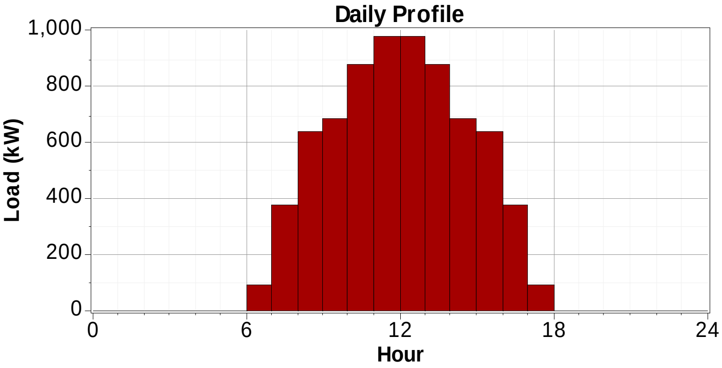

Figure 4. Simulation results of daily load profile in April

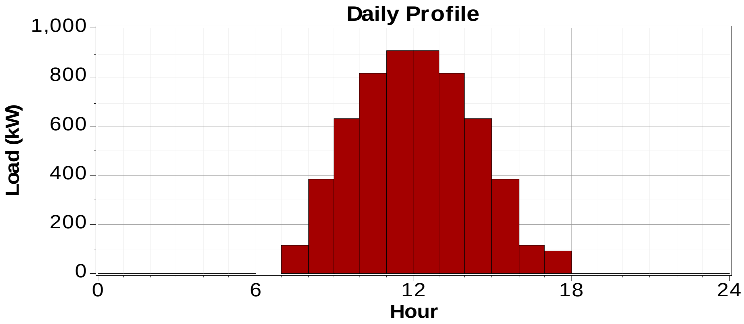

Figure 5. Simulation results of the useful heat gain

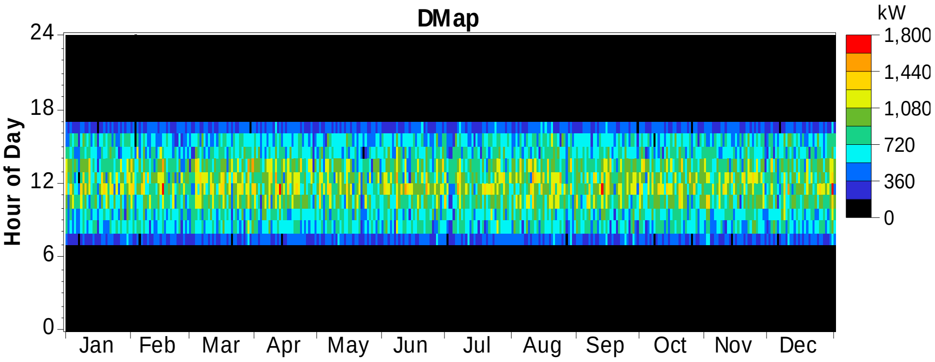

Figure 6. Simulation results of useful heat gain

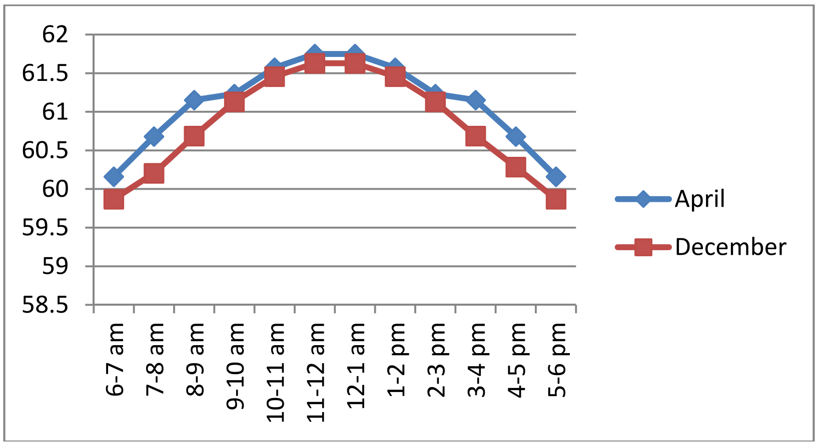

Figure 7. Results of exit temperature in April and December

Figure 3 shows resultsof absorbed flux, Sin April and December in time zones. The absorbed flux, S is the most at 11-12 am and 12-1 pm in April. In December, the absorbed flux is the most at 11-12 am and 12-1 pm. Figure 4 and figure 5 show simulation results of daily load profile in April and December with twelve time zones. The most useful heat gain is 974.6213 kW and the least useful heat gain is 89.2860 kW in April. The most useful heat gain is 907.2462 kW in April and the least useful heat gain is -72.7649 kW in Decmber. Figure 6 shows simulation results of useful heat gain in twelve time zones. Figure 7 shows results of exit temperaturein April and December [5].

4. TWO-TANKS OF THERMAL STORAGE

In The two-tank thermal storage can be integrated into a parabolic trough plant. The basic operating strategy is to charge thermal storage when the HTF flow rate exceeds the design flow rate for steam generation. During charging, molten salt leaves the cold tank extracts heat from the HTF, and then enters the hot tank. The temperature of the HTF heated by discharging salt will be lower than the HTF temperature directly from the solar field because the heat has passed through two heat exchangers and an associated heat loss inside the hot tank. This decrease in temperature will result in a decrease in power generation. The hot and cold storage tanks as shown in Figure 8 were identical with only the temperature of salt varying. For a desired increase in thermal storage, the tank volume and area must increase. The surface area is 39 meter and tall tank is 19 meter. The height was approximated to be 11.7 meters. [6].

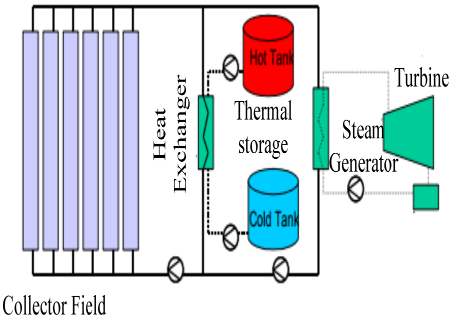

Figure 8. Schematic of a Two-tank Thermal Storage System

5. DESIGN CALCULATION OF THREE-PHASE 1 MVA AC SYNCHRONOUS GENERATOR

Specification	Three-phase turbo alternator generator
Output capacity	1 MVA
Generator output voltage	11 kV
Phase voltage	6350 V
Power factor	0.8, lagging
Speed	3000 rpm
Frequency	50 Hz
Number of poles	2 poles
Type of Drive	Steam Turbine

Equations of three-phase turbo alternator for parabolic trough solar thermal

$$D = \frac{v}{\pi \times n_s} \tag{4}$$

$$D^2 L = \frac{Q}{K' n_s} \tag{5}$$

$$\tau_p = \frac{\pi D}{p} \tag{6}$$

$$E_p = 4.44\, f k_w \phi T_{ph} \tag{7}$$

$$B_t = \frac{\phi}{N_t \times b_t \times L_i} \tag{8}$$

$$R_f = \frac{\rho L_{ml} T_f}{a_f} \tag{9}$$

$$I_R = I_{ph} \times R_s \times k_{dav} \tag{10}$$

$$\lambda_s = \frac{h_1}{3b_s} + \frac{h_2}{b_s} + \frac{2h_3}{b_s + b_o} + \frac{h_4}{b_o} \tag{11}$$

$$\phi_s = 2\sqrt{2}\mu_o I_{ph} L_s \lambda_s T_c \tag{12}$$

$$AT_a = \frac{1.35 T_{ph} I_{ph} k_w}{p} \tag{13}$$

$$AT_{fo} = AT_a \times S.C.R \tag{14}$$

$$h_f = \frac{I_f T_f}{10^4 \sqrt{d_f S_p P_f}} \tag{15}$$

Table 4. Symbol and Description for Three-phase Turbo Alternator

Symbol	Speed (rpm)
D	Internal diameter of stator
τ_p	Pole pitch
B_t	Width of tooth at gap surface
φ	Pole arc
N_t	Number of teeth per pole arc
R_F	Resistance of stator winding per phase
L_{ml}	Mean length of turn
k_{dav}	Average loss factor
λ_s	Specific slot permenance
h_1	Space coupled by insulated conductor in the slot
h_2	Space above the conductor and below the wedge
h_3	Space occupied by wedge
h_4	Space occupied by wedge
b_o	Slot opening
ϕ_s	Slot leakage flux
AT_a	Armature ampere turns per pole
AT_{fo}	No load ampere turn per pole
h_f	Height of field coil
d_f	Depth of field coil
S_f	Space factor
P_f	Permissible loss/m^2

As the rotor slot pitch is 8.14 cm, so the two conductors with 3.8 mm side can be accommodated in the slot foe 1 MVA, width wise. [7], [8].

As a result, 47 conductors will be arranged in a slot, depth wise for 1 MVA. Insulation provided in the slot must be in a position to withstand.

(i) Great mechanical stresses and
(ii) The factors which are due to expansion of slot contents having different thermal expansion coefficient. Insulation on the field coil is provided as follows:
(i) 0.5 mm hard mica cell is provided all round field coil.
(ii) Over the hard mica cell, a 1.5 mm flexible mica cell is provided on the field coil.
(iii) Lastly a steel of 0.6 mm enclose the whole field coil [9], [10].

In addition to the above, various turns slot height is separated from each other by 0.3 mm pressed mica separators.

Slot width	mm
Space occupied by copper conductor, 2 × 3.8	7.6
Mica separator, 1 × 0.3	0.3
Hard mica cell on the conductor, 3 × 0	1.5
Flexible mica cell on the conductor, 3 × 1.5	4.5
Steel cell over the conductor, 2 × 0.6	1.2
Mica strip in the slop, 2 × 0.6	1.2
Slackness	0.9
Total slot width	17.2 mm
	1.72 cm

Slot depth:	mm
Copper conductors, 47 × 4	188.0
Mica separators, (47 – 1) × 0.3	13.8
Hard mica cell on the conductor, 3 × 0.5	1.5
Flexible mica cell on the conductor, 3 × 1.5	4.5
Steel cell over the conductor, 2 × 0.6	1.2
Mica bottom strip in the slot	2.0

Copper strip under the wedge	25.0
Slackness	1.9
Total slot depth	237.9 mm 23.79 cm

Table 5. Results for Three-phase Turbo Alternator generator

Resistance of the field winding	2.88 ohm
Copper loss in each field coil	184.32 W
Total losses in all coils	364.64 W
Brush contact loss with 1 volt, drop at each brush	16 W
Total field copper losses	384.64 W
Input to the exciter	437.09 W
Exciter losses	54.45 W
Friction and winding losses	8 kW
Area of the tooth,A_t	0.0164 m^2
Volume of the tooth	0.00211 m^3
No of teeth	24
Volume of all teeth	0.05064 m^3
Weight of the teeth	394.992 kg
Flux density in the teeth	1.78 Tesla(assumed)
Losses per kg of materials for 0.5 mm plates	28 W
Total losses in the teeth	11.06 kW
Sectional area of the stator core	0.2902 m^2
Volume of the stator core	1.522 m^3
Weight of the stator core	601.19 kg
Flux density in the teeth	1.2 Tesla(assumed)
Losses per kg of materials for 0.5 mm plates	12 W
Total losses in the stator core	7.224 kW
Total iron losses	18.284 kW

Efficiency,

Total losses	kW
Total iron losses	18.28
Total losses of stator	2.83
Total field copper losses	0.385
Exciter losses	0.052
Friction and winding losses	8
	29.55 kW

Otput of the alternator $=1\times10^3\times0.8=800$ kW

Efficiency$=\frac{800}{800+29.55}=96.4\%$

6. CONCLUSION

Technical evaluation of a Solar Parabolic Trough System was performed in Wyargyi village, Thazi Township in Mandalay Division. From the temperature data of year 2014, the maximum temperature is occurred at April and the minimum temperature is occurred at December. The heat gain from collector to receiver, working fluid heat energy, and the storage system are also concerned with temperature variation. In this paper, development of two-tank storage system that uses molten salt as the heat transfer fluid is described. The detail design calculations of absorbed flux, the useful heat gain, exit temperature, and three-phase turbo alternator design are presented and calculated. Simulation results of daily load profile and useful heat gain in April and December in twelve time zones are presented. At present, there is still no practical experience in the operation of this power plant technology in Myanmar. The solar thermal system can reduce carbon emission and cost of transmission losses.

ACKNOWLEDGEMENTS

The author is deeply grateful to her parents, U Tun Kyi and Daw Ohm Kyin for their supports and encouragement to attain her destination without any trouble and all the persons who share the trouble of the author on any situation in trying this paper.

Moreover, the author would like to thank sisters. Thanks to all her teachers, friends, and family members, for inspiring and motivating her. The author is deeply grateful to all the persons who helped directly or indirectly towards the accomplishment of this paper.

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